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BEZSMERTNA V.I., IELINA T.V., HALAVSKA L.Ie.
Kyiv National University of Technology and Design

ANALYSIS OF CFD SIMULATION OPPORTUNITIES FOR DETERMINATION OF KNITWEAR QUALITATIVE CHARACTERISTICS

Purpose. *To develop method for determining knitted fabric's characteristics for special purposes by using modern computer programs.*

Methodology. *In the work methods for analysis and synthesis of scientific, technical and patent literature in the modeling field of physical and mechanical processes in various industries were used. Tools that are embedded in the Autodesk AutoCAD software were used to predict properties of the materials CFD software and 3D modeling.*

Results. *The number of software analysis packages and their capabilities. Best software was selected for determining knitted fabrics quality characteristics.*

Scientific novelty. *To identify ways of improving the method for determining physical and mechanical characteristics of jersey special canvas. Also: CFD modeling capabilities were described for determining knitted fabric's quality; were defined and justified demands of 3-D models for the prediction of high-quality physical and knitted fabrics mechanical properties using computer tools.*

Practical value. *The method was offered to determine the knitted fabrics properties using specialized software. This technique allows the help of 3D modeling to recreate experiments in close to real conditions in the laboratory equipment.*

Keywords: *CFD, modeling, knitwear, physical and mechanical properties.*

Introduction. Nowadays, with the development of computer technology and continuous improvement of engineering research algorithms, modern engineers have more possibilities for virtual tests of complex hydro - gas-dynamic testing products. This dramatically reduces the need for costly testing physical prototypes. In some cases the need for real tests is eliminated completely. This is especially true in specific areas which makes it difficult to conduct, for example, in outer space or in the area of a disaster.

In such cases it is advisable to use modern methods of computational aero-hydrodynamics-CFD (Computational Fluid Dynamics).

Objectives. The aim of this work is to analyze the possibilities of CFD simulation in terms of suitability for predicting jersey characteristics for special purposes.

CFD technology - a combination of physical, mathematical and numerical methods designed to calculate the liquids and gases flow properties. This modeling method has the greatest opportunity to analyze the data obtained due to the coloring of the calculation results. The progress of computer technology in aero and hydrodynamics allows virtual full replacement of natural physical experiments conducted in a wind tunnel with computing experiment, and the resulting information contributes to understanding of physical processes.

The first development of CFD-modeling technology started at the early 80th. Thanks to the program's versatility they were widely used in various scientific fields and industrial production. CFD-models can solve a variety of tasks – calculate the flow of aircraft wing to combustion of the material in furnaces, produce glass or to simulate movement of blood through the vessels and so on. CFD- modeling is used by many well-known companies in the aviation - and affecting the car production industry for modeling aerodynamic forces. Design flow processes programs are high-tech products, their creation required more than a thousand man- years of skilled programmers work and physicists from around the world. CFD programming used in various fields, namely: instrumentation, electronics and lighting; valves, nozzles, throttles; pumps, compressors, turbines, fans; heat exchangers, coolers, air conditioners; construction, architecture, AEC, HVAC, BIM.

The question of the need for virtual experiments to study the nature of the deformation of knitted fabrics for special purposes under power loads, thermal and gas-exchange processes in knitted fabrics and products arose long ago. This method of determining the jersey quality characteristics allows to set knitting parameters while in the design phase, ensuring the production of knitwear with desired properties. Simulation provides adequate jersey dimensional geometric models. In addition, one of the key elements in implementing virtual experiments is to determine the best software that will predict physical and mechanical characteristics of the fabric.

Research results. Currently there is a lot of works on the topic of creating 3D jersey models with appropriate structure. Scientists use different ways to obtain three-dimensional structures that meet the specifications of the real fabric. So in their works [1, 2] the authors used X-ray micro-computer tomography. This method gives very accurate information about the fibrous structure geometry, but it can be only applied to already produced fabric.

Other researchers created structure’s topology and improved it by mechanical methods. This is one of the core methods that allow reproduction of the knitwear geometry in a short period of time. The first scientists who created these structures were Pierce and Kemp [6, 7].

In works [3-5] the model of complete production process is represented. For example, in his work R. Ackerman [4] reproduces the entire process, from weaving machine to creating the finished canvas. This method requires many calculations, which in turn takes time.

In works [8,9,10] we have developed a theoretical basis for creating 3D models of the jersey color weaves and tested the possibility of using these models for computer analysis of the jersey properties and behavior.

Erdan Kesov in his article [11] examines the most common geometric modeling methods of textile structures. For comparison, he chose geometry using only the key points and the geometry using key points with well-defined curves between these points. The author describes the software packages for simulating knitted fabrics and analyzes their capabilities at the moment.

E. Kesov conditionally divided the creation process of multiple textile structure on different levels. Zero level is fiber, the first - thread, the second - twisted yarn, third is knitwear, and fourth is rope or clothing. The scientist's work described the designs to 3-level simulation.

In article [12] an overview of the existing geometric and physical models of loops knitted fabric is presented. Author's work describes a method of imaging the mentioned loop for future analysis. In this way the change of contour shape is possible using polynomial functions and determining curvature center loop. The final result of this work is the dependence of circuit loop parameters during deformation in the direction of columns. Knitwear was checked in operation. It was made of special material NiTi, characterized as superelastic. The elastic properties of NiTi are displayed on the properties of the loop, which proves the correctness of the jersey imaging.

To determine the deformation properties of knitwear the adequate knitted fabric structure is not enough. For such modeling there is the need for a more flexible knitted fabric model.

Simulation process consists of two key phases. It is creation of 3D models in computer environment (modelling) and conduction of virtual experiments with it (simulation) [13]. Accordingly, the accuracy of analytical calculations in CAE systems depends on the adequacy of the models created in the first stage of consideration of all object modeling essential characteristics. In terms of built-in tools suitable for automation hydrodynamic calculations determining the knitted fabrics quality characteristics results can be achieved by such well-known software like ANSYS FLUENT and ANSYS CFX, Flow Vision, OpenFOAM, SigmaFlow, Autodesk Simulation CFD and others.

For model to be adequate many characteristics of the object must be considered. In previous studies we identified indicators of jersey breathability [14] using software Autodesk Simulation CFD. Virtual experiment was conducted using a 3D model of the structure of knitwear created in AutoCAD software environment [10]. This model takes into account such factors of jersey structure as loopy step; height looped series; horizontal density; vertical density; thick knitwear; the length of thread in the loop; penetrating porosity. Also material was tested on air flow and steel tube.

For a more detailed analysis of the knitted fabric properties for special purposes, which in the course of the product can withstand various kinds of power loads, and determine their quality, including tensile deformation and fracture looped structure, it is not enough. Besides the above-mentioned jersey characteristics and software environment conditions also must be specified: material properties; commodity composition of threads or fibers (wool, flax, etc.); filament threads; thread twist; material density; viscosity; thermal conductivity; specific heat; crease; radiated capacity; roughness.

These figures can change or leave the default for the selected material depending on the purpose of knitwear and physical and mechanical characteristics to be figured out. In addition, when the material characteristics need to be determined it is necessary to specify if it is fixed or variable, and then set the conditions of the script. Material properties can be evaluated in these conditions, and / or continuously maintained, or used the original ones.

CFD modeling fits the determining the knitted fabrics quality characteristics because the software allows to use simple geometric objects (loop structure), as well as complex parts or even assemblies (structure jersey). For a more precise calculation there is the ability to adjust the size and density of the mesh in critical areas such as the intersection of two loops.

Tool to determine the qualitative properties of knitted fabrics is offered in such software products as: Autodesk Simulation CFD, ANSYS FLUENT and ANSYS CFX, Flow Vision, OpenFOAM, SigmaFlow and others.

Autodesk Simulation CFD is software that has a complete set of tools for the simulation of heat and fluid flow processes. This helps to predict the behavior of products during use, optimize design and thoroughly check projects before transmission into production. For convenient use Autodesk Simulation CFD is equipped with the following tools: modeling-oriented interface, automated grid for Finite Element Analysis of size selection and specification, modeling kernel Accelerant, and special environment for project learning. The software is used in the design of industrial equipment, medical devices, consumer goods, oil and gas industry and the automotive industry. Autodesk Simulation CFD provides the following features:

• automation of project studying - a set of tools that will optimize process design and improve analysis efficiency;

• important decision-making center- a convenient powerful environment for comparing design options;

• project-checking center - a visual environment for learning project that simplifies and accelerates the process of decision-making;

• model-oriented interface - provides multiple ways to interact with the model at any time;

• customizable database of materials - flexible materials management.

ANSYS - the universal program system of finite-element (FEM) analysis of existing and evolving over the past 30 years, it is quite popular among professionals in the field of automated engineering calculations (CAD or CAE, Computer-Aided Engineering) for solving linear and non-linear equations stationary and non-stationary spatial problems and mechanics of deformed solid forms and structures, problems in mechanics of gas and liquid, heat exchange and heat transfer, acoustics, electrodynamics, mechanics and related fields.

ANSYS CFD technology provides access to a well-known software products: ANSYS FLUENT and ANSYS CFX. These are the main products for general purpose tasks hydro and gas dynamics offered by ANSYS Inc. Programs are available separately. These two program solvers were developed independently and despite some similarities have several significant differences. They lie in the method of integrating the equations of fluid flow and strategies for solving equations. ANSYS CFX platform is fully integrated into ANSYS Workbench.

ANSYS CFX software uses finite element mesh (numerical values in the grid), similar to those used in the analysis of strength for the sampling area. Unlike ANSYS CFX, ANSYS FLUENT product uses a mesh of finite volumes (numeric value in the centers of holes). In the end, both approaches form the equation for finite volumes, which ensure conservation values of the flow, which is a prerequisite for exact solutions of the problems with hydro gas dynamics. In ANSYS CFX special emphasis is set on solving the basic motion equations (coupled algebraic mesh) and ANSYS FLUENT offers several approaches to solving (method based on the density split, method based on pressure associated, method based on pressure). Both programs contain valuable physical simulation capabilities for accurate results.

ANSYS solvers for liquids and gases contain over a thousand man-years of research and development. These efforts are expressed in ANSYS software advantages over other similar programs, especially in experience, reliability, breadth and depth.

FLOWVISION. Program computational complex for aero - and hydrodynamics. FlowVision is designed for mathematical modeling of various physical processes and of industrial infrastructure and nature, as well as the operation of vehicles. FlowVision based on the numerical solution of three-dimensional stationary and non-stationary dynamics equations of gas and liquids, which include the laws of conservation of momentum, mass (Navier-Stokes equation), state equation. To calculate the complex movements of liquid and gas, accompanied by additional physical phenomena, such as turbulence, combustion, porous medium, heat, mass transfer and so on, in the mathematical model were included additional equations describing these phenomena. FlowVision uses conventional volumetric approach to approximate equations of mathematical model. Navier-Stokes equations are solved by splitting on physical processes (projection method MAC). FlowVision based on such technologies of computational fluid dynamics and computer graphics:

• rectangular grid design with a local settlement centers fragmentation;

• approximation of curved boundaries of the settlement area by subgrid division geometry;

• import CAD systems geometry and finite-element through the surface of the grid;
• program core written in C++;
• a client-based server architecture;
• user interface – for operational systems MS Windows and Linux;
• simulation results analysis system using high-quality graphics based on OpenGL.

OpenFOAM - open integrated platform for numerical modeling of continuum mechanics problems. OpenFOAM – free program for computational fluid dynamics tools for operations with fields (scalar, vector and tensor). It is a one of "complete" and known applications designed for FVM-computing. Initially the program was designed for strength calculations, but the result of years of academic and industrial development up till now allows us to solve many different problems of continuum mechanics (though it isn't limited to it), including:

• calculations of strength;
• heat conduction problems in solids;
• multiphase tasks including chemical reactions describing the component stream;
• tasks associated with the estimated net deformation;
• conjugated problems;
• other tasks, which require mathematical formulation solving differential equations in partial derivatives in the complex geometry of the environment;
• parallelization of calculation to run on multiprocessor systems (including cluster systems).

At the core code is a set of libraries that provide tools for the solution of partial differential equations derived in time and space. The working language of the code is C++. In terms of the language most mathematical differential and tensor operators in the code equation (to broadcast an executable file) can be presented in an understandable form. The method and sampling solution for each operator can be selected by the user in the process of calculation. Thus, encoding is fully encapsulated and separated. This is the concept of computational grid method, sampling the basic equations and methods of solving algebraic equations.

SIGMAFLOW. The program SigmaFlow - a universal commercial software product for a wide class of problems: fluid dynamics, heat transfer and combustion. SigmaFlow is a further development of AeroChem program, developed since 1993. Specialized versions are used by a number of researchand design organizations and in the education. The program development is provided in the implementation of projects under grants and contracts for research.

The program SigmaFlow can simulate following processes:

• steady and unsteady fluid and gas flow;
• non-Newtonian fluids flow;
• turbulent flows using RANS and hybrid RANS / LES models;
• conductive and radiative heat transfer;
• chemical reaction and mixing processes in multicomponent mixtures;
• combustion of gaseous, liquid and solid fuel;
• dispersed phase movement in the carrier flow (solid particles, droplets, bubbles);
• drying processes and pyrolysis, chemical reaction of the dispersed phase;
• free boundary problems;
• movement of solids in the gas stream;
• deformation of solids;

• flow with phase transitions (melting - crystallization);

• cavitation flow;

• volumetric flow of forces.

SigmaFlow program like all universal programs allows you to create geometry of calculated object prepare estimated, perform own calculations and analyze simulation results using graphical tools. Recent versions allow high-performance parallel computing on cluster systems running Windows operating systems or Linux. The numerical technique embedded in a program is based on the finite volume for unstructured grids, provids conservative algorithm and allows to model processes in geometrically complex objects. For approximation of differential equations uses sustainable schemes of high accuracy order. The interaction between velocity and pressure fields is realized using the procedure of splitting. Systems with difference equations are solved by an iterative method using multigrid methods.

Conclusions. Analysis capabilities allowed finding out that all of the listed above software packages above to perform 3D modeling are suitable for determining the quality characteristics of knitted fabrics. We suggest performing 3D modeling knitwear patterns in the program Autodesk Autocad. Autodesk Simulation CFD software are from the one kind. This allows avoiding additional conversion when opening files from Autocad 3D models of structures designed knitwear in Autodesk Simulation CFD.

Thus, with Autodesk Simulation resources CFD with available 3D model of jersey virtual experiments could be implemented to determine the quality characteristics of knitted fabrics. In the absence of technological equipment it gives the opportunity to set optimal structure parameters that ensure predictable properties of jersey. Today it is especially important for special purpose knitwear produced from high strength materials.

This method can significantly reduce the time and cost to manufacture prototypes for knitting equipment. It does not require additional laboratory equipment and comfortable in operating. Improved accuracy of calculations can be achieved by improving the geometry of the 3D jersey structure model of given physical and mechanical material characteristics, including its bending stiffness, density substances, twist, etc.

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АНАЛІЗ МОЖЛИВОСТЕЙ CFD МОДЕЛЮВАННЯ ДЛЯ ВИЗНАЧЕННЯ ЯКІСНИХ ХАРАКТЕРИСТИК ТРИКОТАЖУ

БЕЗСМЕРТНА В.І., ЄЛІНА Т.В., ГАЛАВСЬКА Л.Є.
Київський національний університет технологій та дизайну

Мета. *Розробка методу визначення якісних характеристик трикотажних полотен спеціального призначення з використанням сучасних комп'ютерних програм.*

Методика. *Використано методи аналізу та синтезу науково-технічної та патентної літератури у сфері моделювання фізико-механічних процесів в об'єктах різних галузей та прогнозуванні їх властивостей за допомогою CFD програм, а також інструменти 3D моделювання, вбудовані у програмні продукти Autodesk AutoCAD.*

Результати. *Проаналізовано ряд програмних пакетів та їх можливості. Обрано програмне забезпечення для визначення якісних характеристик трикотажних полотен.*

Наукова новизна. *Полягає у виявленні шляхів удосконалення методу визначення фізико-механічних характеристик трикотажу спеціального призначання. При цьому: охарактеризовано можливості CFD моделювання для визначення показників якості трикотажних полотен; визначені та обґрунтовані вимоги до 3-D моделей для якісного прогнозування фізико-механічних властивостей трикотажу з використанням* *комп'ютерних засобів.*

Практична значимість. *Запропоновано метод визначення властивостей трикотажних полотен з використанням спеціалізованих комп'ютерних програм. Дана методика дозволяє за допомогою засобів 3D моделювання відтворити експерименти в умовах, близьких до реальних умов на лабораторному обладнанні.*

***Ключові слова**: CFD, моделювання, трикотаж, фізико-механічні властивості.*

АНАЛИЗ ВОЗМОЖНОСТЕЙ CFD МОДЕЛИРОВАНИЯ ДЛЯ ОПРЕДЕЛЕНИЯ КАЧЕСТВЕННЫХ ХАРАКТЕРИСТИК ТРИКОТАЖА

БЕССМЕРТНАЯ В.И., ЕЛИНА Т.В., ГАЛАВСКЯА Л.Е.
Киевский национальный университет технологий и дизайна

Цель. *Разработка метода определения качественных характеристик трикотажных полотен специального назначения с использованием современных компьютерных программ.*

Методика. *Использованы методы анализа и синтеза научно-технической и патентной литературы в области моделирования физико-механических процессов в объектах различных отраслей и прогнозирования их свойств с помощью CFD программ, а также инструменты 3D моделирования, встроенные в программные продукты Autodesk AutoCAD.*

Результаты. *Проанализирован ряд программных пакетов и их возможности. Выбрано программное обеспечение для определения качественных характеристик трикотажных полотен.*

Научная новизна. *Состоит в выявлении путей совершенствования метода определения физико-механических характеристик трикотажа специального назначения. При этом: охарактеризованы возможности CFD моделирования для определения показателей качества трикотажных полотен; определены и обоснованы требования к 3-D моделям для качественного прогнозирования физико-механических свойств трикотажа с использованием компьютерных средств.*

Практическая значимость. *Предложен метод определения свойств трикотажных полотен с использованием специализированных компьютерных программ. Данная методика позволяет с помощью средств 3D моделирования воспроизвести эксперименты в условиях, близких к реальным условиям на лабораторном оборудовании.*

***Ключевые слова**: CFD, моделирование, трикотаж, физико-механические свойства.*